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**Travelling Field Machine****Description**

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**Field of the Invention**

The present invention relates to a travelling field machine. The invention relates, in particular, to a travelling field machine with a stator and a rotor, each of which comprising at least one stator coil or one rotor coil, respectively, with the stator or the rotor, respectively, comprising a soft magnetic iron body with a stator or rotor back, respectively. At the soft magnetic iron body spaced grooves are formed, generating teeth, which are oriented towards an air gap which is defined by the stator with the rotor.

**Definition of Terms**

The term "travelling field machines", i.e. asynchronous, synchronous, reluctance machines etc. covers motors as well as generators, whereby it is of no significance in particular for the invention whether such a machine is designed as a rotating machine or, for example, as a linear motor. Moreover, the invention may be applied both to internal rotor machines and external rotor machines.

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**Background of the Invention**

In the reduction of the volume of highly efficient electrical machines the form of construction and the arrangement of the conductors play a decisive role. Conductors with a minimum length in the winding overhangs at a high utilisation of the space reduce the ohmic losses and increase the power density of the electrical machine.

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Due to the fact that the ohmic losses in the control and in the winding are proportional to the current to be connected, a certain conductor length must be provided in the magnetic field in order to generate an induced back voltage corresponding to the desired high control voltage in a conductor arrangement of a resistance as low as possible.

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Conventional electrical machines in their majority are wound with continuous wires - mostly with round cross-section. Though a thin flexible wire may easily be placed into the grooves, it has the disadvantage of a poor space utilisation in the grooves and winding overhangs. Wires with round cross-section cannot fully utilise the cross-sectional area of the groove. In

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order to increase the filling factor of the grooves (total wire cross-sectional area/groove sectional area) so-called pre-formed coils are employed wherein normally rectangular conductor bars are inserted into the grooves, which are adapted to the geometric cross-sectional shape of the groove and which are connected at their ends via end windings in order to form the coils. In order to the reduce the ohmic losses in the winding overhangs, i. e. in the conductor portions of the coils protruding from the grooves, a number solution approaches is known which are directed to the design of the geometry of the winding overhangs.

### State of the Art

From DE 38 03 752 A1 a stator for a three-phase generator is known, whose stator core assembly comprises grooves in which stator windings are arranged. The stator winding portions within the grooves have a rectangular cross-section and the stator winding portions forming the coil ends outside the grooves have a circular cross-section. The stator winding portions with the circular cross-section are formed by hollow cylindrical conductors. The stator winding portions with the rectangular cross-section are formed by compression of the hollow cylindrical conductor.

From GB 1 329 205 it is known to manufacture the windings as cast bodies wherein the end portions (protruding from the grooves) have a larger cross-section than the conductor portions within the grooves.

From EP 1 039 616 A2 a travelling field machine is known whose stator carries a stator coil. The stator has a soft magnetic iron body with a stator back in which spaced grooves are formed, generating teeth. The stator coils have conductor bars arranged in the grooves and end windings arranged at the end faces of the stator, which connect the conductor bars. The end windings of the stator coils are arranged transversely to the groove bottom and project above the groove bottom towards the stator back. The stator portions in the end face area of the stator project beyond it in a radially inward direction. The end windings and the conductor bars are riveted together by means of pins.

From DE 1 123 038 and DE 101 56 268 stators for electrical machines are known which comprise at least one pipeline which runs around the periphery of the winding overhang in a circumferential direction. A cooling agent flows through each pipeline, which dissipates the heat coming from the winding overhang. The pipeline of the stator known from DE 1 123 038 has to be attached and secured at the winding overhang by means of a complicated arrangement of copper strips and bolts. The pipelines of the stator known from DE 101 56 268 are fixed at locally very limited parts of the periphery of the winding overhang. In both

cases, the thermal contact between winding overhang and coolant is therefore far from optimal.

From DE 101 43 217 a technically advanced travelling field machine is known whose stator or rotor, respectively, has end windings which have a certain thickness essentially transverse to an air gap located between the stator and the rotor, which thickness is related to the thickness and the number of the conductor bars and to the thickness of the stator or rotor back, respectively.

#### 10 **Problem on which the Invention is Based**

The above explained known arrangements suffer from the drawback that they meet the requirements with respect to power density and reliability only partially, as are specified for several applications. In particular with applications in which the electrical machine is subjected to elevated ambient temperatures (approx. more than 100°C) the ohmic losses in the coils increase considerably due to the increased higher resistivity of the coil material and contribute considerably to the total losses. The machine should preferably also comprise a design which is thermally efficient and uncomplicated in its assembly.

#### **Inventive Solution**

20 For the solution of these problems the invention teaches a travelling field machine of the above mentioned type with a stator and a rotor, each of which comprising at least one stator coil or one rotor coil, respectively, with the stator or the rotor, respectively, comprising a soft magnetic iron body with a stator or rotor back, respectively, in which spaced grooves are formed, generating teeth and the stator or rotor coils, respectively, comprising conductor bars arranged in the grooves of the stator or the rotor, respectively, and end windings arranged at the end faces of the stator or the rotor, respectively, which connect the conductor bars, which are connected with the conductor bars in an electrically conductive manner in order to electrically connect conductor bars of spaced grooves, with the end windings forming a stacked packet from which at least one thermally conductive element is projecting which extends to a heat sink. Each end winding is formed from an essentially plane thin sheet which in its radial extension relative to the longitudinal centre axis of the stator or the rotor, respectively, extends approximately to the or into the, respectively, heat sink (30).

35 This design permits a maximum utilisation of the available space (both in the axial and the radial, or lateral, respectively, direction) and at the same time a power optimisation of the electrical machine with a very high reliability in operation; in particular in applications in which the electrical machine is subjected to elevated ambient temperatures (e. g. approx. more than 100°C).

### **Embodiments and Developments of the Invention**

In a preferred embodiment of the invention the thermally conductive element is in a thermal (surface) area contact with at least one of the end windings in order to constitute a thermal connection to the heat sink. Alternatively, the thermally conductive element may be designed as an extension of one of the end windings and project from same in order to constitute a thermal connection to the heat sink.

Each of the thermally conductive elements is thereby protruding - dependent on the design - into the heat sink or is connected with its outer wall in a thermally conductive manner.

The heat sink is preferably a fluid cooling means which is arranged coaxially with the conductor bars.

Each of the end windings may be formed from an essentially plane thin sheet which in its radial extension relative to the longitudinal centre axis of the stator or the rotor, respectively, extends approximately to the or into the, respectively, heat sink.

The end windings formed from an essentially plane thin sheet may be oriented relative to the longitudinal centre axis of the stator or the rotor, respectively, either essentially transversely or essentially tangentially. In other words, the end windings are oriented either flat or upright. The thermally conductive elements have essentially the same orientation as the end windings.

The conductor bars have a pin each at their ends which engages a correspondingly shaped recess at one end of the end winding in order to make an electrically conductive connection.

The electrically conductive connection of the ends of the end windings and the ends of the conductor bars may be made by electric impulse welding. Alternatively, the ends of the end windings and the ends of the conductor bars may also be joined in an electrically conductive manner by laser welding.

Depending on the insulation requirements to be met by the coils of the inventive travelling field machine, the conductor bars and/or the end winding are provided with a synthetic material, ceramic, or enamel coating. It is, however, also possible to make the conductors from aluminium so that the mutual insulation of the conductor bars or of the end windings, respectively, is given by an alumina layer.

In a corresponding manner the thermally conductive elements may be formed from copper, aluminium, or alloys containing said metals. Alternatively, the thermally conductive elements may also be formed from aluminium nitride.

- 5 The heat sink is preferably formed by wall sections which together with the thermally conductive elements define a channel for a heat dissipating fluid, in particular, water or oil.

In a preferred embodiment of the inventive travelling field machine the wall sections of the heat sink are formed by annular elements which are concentric to the longitudinal centre  
10 axis of the stator or the rotor, respectively, with neighbouring annular elements each accommodating thermally conductive elements between them.

For the formation of the cooling channel through which the heat dissipating fluid is flowing the wall sections of the heat sink are joined with the thermally conductive elements by braz-  
15 ing, welding, adhesive bonding, or otherwise joined so as to be fluid tight and essentially dimensionally stable.

The wall sections of the heat sink and the thermally conductive elements are preferably made from copper, aluminium, or other thermally conductive materials. Depending on pecu-  
20 liarities of the field of application of the travelling field machine, however, other materials with good thermal conductivity may be employed as well.

There is also the possibility with electrical machines whose stator or rotor, respectively, is provided with a cooling channel to connect the heat sink for the end windings with the heat  
25 sink for the stator or the rotor, respectively, in a fluid conducting manner. This reduces the expenditure for the fluid lines. Incidentally, the heat sink for the end windings may also be mechanically connected with the fluid channel.

This fluid channel is preferably arranged at the back of the stator or the rotor, respectively,  
30 as a heat sink.

Further characteristics, properties, advantages, and possible modifications will become apparent for those with skill in the art from the following description in which reference is made to the accompanying drawing.

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### **Brief Description of the Drawings**

Fig. 1 shows a schematic cross-sectional illustration of a stator for an electrical machine according to the invention.

Fig. 2 shows a schematic longitudinal sectional illustration of a stator for an electrical machine according to Fig. 1 along line II-II.

## 5 Detailed Description of Preferred Embodiments

In the drawings a stator 10 for an electrical machine according to the invention of an external rotor machine (not shown in detail) is illustrated, with the invention being also applicable to an internal rotor machine. In the present embodiment, the stator 10 is built from stacked sheets 11, but could also consist of iron particles which are pressed and sintered to the appropriate shape.

The stator 10 is a soft magnetic iron body with a stator back 10a and has grooves 12 arranged next to one another, by means of which the winding chambers for the respective stator coil windings 14 are formed. In the shown embodiment the winding chambers 12 have an essentially rectangular cross-section, with slots 16 in the side facing towards the rotor (not shown). Thus, teeth 18 are formed between two slots 16 each (see Fig. 1). The end windings 22 have an essentially parallel orientation relative to the end face of the stator or rotor, respectively, or to the sheets 11.

Each stator coil 14 is formed by conductor bars 20 with an essentially rectangular cross-section, which are inserted in the winding chambers 12 and joined by end windings 22. The end windings 22 of all windings together form winding overhangs 24 (see Fig. 2). The cross-section shown in Fig. 2 illustrates only one end of the conductor bars or one end face, respectively, of the stator. The other not shown end is a mirror image equivalent.

As shown in Fig. 2 the conductor bars 20 of the electrically conductive connecting end windings 22 form a stacked packet 26 from which between two end windings 22 each a thermally conductive element 28 is protruding which extends towards a heat sink 30 in the form of a fluid channel through which a cooling liquid is flowing.

The thermally conductive elements 28 are in a thermal (surface) area contact with the end windings 22 in order to constitute a thermal connection to the heat sink. For this purpose, the thermally conductive elements 28 extend into the heat sink 30. As can be seen from Fig. 2, the end windings 22 are formed from an essentially plane thin sheet which in its radial extension relative to the longitudinal centre axis M of the stator 10 extends from the respective conductor bar 20 into the heat sink 30.

The conductor bars 20 and the end windings 22 of this embodiment consist of copper and are provided with pins 20a at their ends. Each pin 20a engages a corresponding recess 22a at the end of the relevant end winding 22 in order to make an electrically conductive connection with it. For this purpose, the pin 22a is joined with the recess 22a at the end of the end winding 22 by means electric impulse welding or laser welding so as to be electrically  
5 conductive. It is, however, also possible to dispense with the pins 20a and the recesses 22a and to perform butt welding. Each of the conductor bars and the end windings is provided with a ceramic or enamel coating for electric insulation.

10 The fluid channel 30 through which cooling liquid is flowing and which forms the heat sink is formed by wall sections 30a, 30b which together with the thermally conductive elements 28 define a hollow annular cylindrical channel for heat dissipating fluid. For this purpose, the wall sections of the heat sink 30 are formed by annular elements 30a, 30b which are concentric to the longitudinal centre axis M of the stator 10, with neighbouring annular elements  
15 30a, 30a and 30b, 30b each accommodating thermally conductive elements 28 between them and being welded or brazed with them.

As illustrated in Fig. 1, the thermally conductive elements 28 have a circular segment shape with radial extensions 28a extending to the conductor bars 20 with which they are welded at  
20 the pins 20a. The radially inner portion of the thermally conductive element 28, which extends into the heat sink 30 has a recess 28b which follows the shape of the annular channel of the heat sink 30 in order not to obstruct the flow of the cooling fluid.

As is illustrated in Fig. 2, the stator 10 has an own fluid cooling in the form of a cooling liquid channel 40 at its back 10a. This cooling liquid channel 40 is arranged coaxially with the  
25 fluid channel 30 through which cooling liquid is flowing for cooling the end windings 22. Moreover, the two cooling means are connected via passages 42 in a fluid conducting manner.

The ratios and proportions between the individual parts and portions therefrom as well as  
30 their material thicknesses shown in the figures are not to be construed as being limiting. Rather individual dimensions may differ from the shown ones.